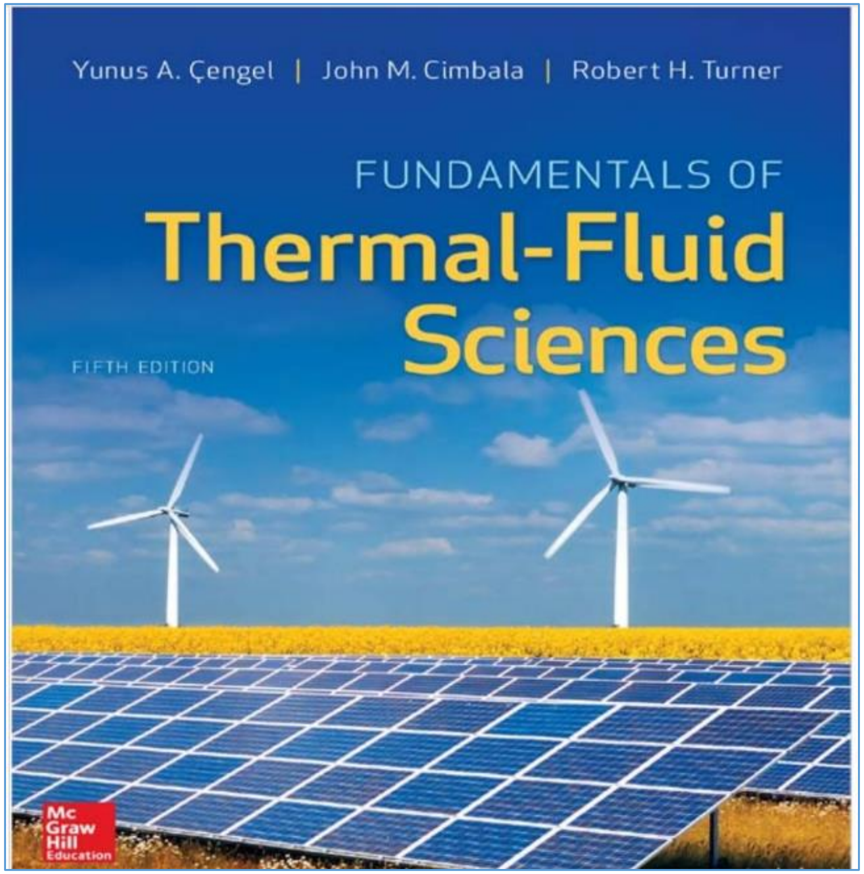
ENGR 35200 Thermal Fluids Engineering

Fall 2023



ENGR 35200, Thermal Fluid Engineering

Fall 2023
Dr. A. Aziz

Course Information

Class meeting…………………..……………. **…………………………………….. MW 2:15 PM- 3:30 PM**
Office location……………………………………………………………………..……………………………………………ATB 220D
Lecture location……...ATB 102
Phone/E-mail (330) 672-1032 / aabdula3@kent.edu
Office Hours …………………………………………..uesday-1:00 Pm – 4:00 pm walk-ins are welcome, All other times by appointment
Teaching Assistant: none

ENGR 35200 THERMAL FLUID ENGINEERING 3 Credit Hours
First and Second Law of Thermodynamics for closed and open systems. Fundamentals of fluid mechanics and heat transfer.
Prerequisite: MATH 22005 or MATH 32051; and PHY 23101.
Corequisite: ENGR 35201.
Schedule Type: Lecture
Contact Hours: 3 lecture
Grade Mode: Standard Letter

Textbook and Required Material:

- **Fundamentals of Thermal-Fluid Sciences, 5th Edition;** Yunus A. Cengel, John M. Cimbala, Robert H. Turner; ISBN: 978-07-802768-0; McGraw-Hill Education, [2016].
- Course Folder located at FlashLine Student Folder.

Recommended References

- https://www.learnthermo.com/examples.php
- https://www.grc.nasa.gov/www/k-12/airplane/heat.html
- https://www.tecquipment.com/thermodynamics
- https://www.unitconverters.net/
- https://www.webqc.org/unitconverters.php

ACADEMIC HONESTY

1. All students must consent and sign the ethics & integrity contract prior to receiving academic credit for work.
2. If the submitted work is the result of a collaborative effort, names of all members and contributors must be clearly indicated.
3. Aeronautics & Engineering require integrity. Document and cite sources accordingly.
4. The use of electronic devices to capture images of online quizzes and exams in order to pass to other students is cheating.
5. The use of Chegg, Course Hero, or any other online source without citation in preparing assignments for grade is a violation of the university's academic honesty.
6. Copying another student's computer code, spreadsheets, documents, handwritten problems is also a violation of university policy regarding academic honesty.

The policy that governs academic honesty is University Policy 3-01.8: Administrative policy regarding student cheating and plagiarism. **If any student is found to have violated the university's policy, the student will automatically receive a grade of "F" for the entire course**.
Cheating means to misrepresent the source, nature, or other conditions of one's academic work (i.e., tests, papers, projects, assignments) so as to get underserved credit. The use of the intellectual property of others without assigning appropriate credit is a serious academic offense.

INSTRUCTOR POLICIES:

Laptop Policy

The use of laptops will not be permitted in class. Laptop screens can be a major distraction to other students, especially if you are surfing the internet instead of paying attention.

Homework Policy

Homework will be assigned on Mondays and will be due on the following Monday. You can submit your homework in digital form (PDF preferred) via email. Your submission should include a title, your name. All work should be shown, and it must be clearly written. Where appropriate, all dimensional units should be included. Unreadable submissions will not be graded. Late homework will not be accepted, except for extreme circumstances or documented illness.

Ethical Conduct:

Students are expected to conduct themselves in a professional manner and uphold the standards expected of the engineering profession. During your academic studies, unacceptable actions include cheating during in-class quizzes or exams, copying homework and/or lab reports, fudging data, etc. During your employment as an engineer, nothing will end your career faster than falsifying data or forwarding inadequate designs. Unethical conduct during your engineering career will be dealt with by your employer and the legal system

Unethical conduct during this class will be dealt with according to the Kent State University Code of Student Conduct that can be found at:

http://www.kent.edu/studentconduct/code-student-conduct

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Withdrawal Deadline:

Check the link below.

http://www.kent.edu/registrar/spring-important-dates

Administrative Policies:

•Attendance. **Students may miss a total of two (2) class periods without penalty**, which is two weeks of the semester. The instructor will take attendance for each class period. Any absences beyond these four will negatively affect the student's attendance grade. Students are responsible for any and all information covered in a class session for which they are absent.

•Electronic devices. Please ensure that all electronic devices are in silent mode. Phones are not allowed during exam periods.

•Calculators. Students will use a calculator for class and exams. Shared calculators are not allowed during exams, and failed batteries are not an excuse for not having one.

Experiential Learning Requirement / Writing Intensive Requirement

Experiential Learning Requirement / Writing Intensive Requirement

Course Learning Objectives (CLOs)

The following table lists the course learning objectives and how they support student outcomes as well as meet the university's experiential learning requirement.

1. Students integrate knowledge from previous coursework to develop a feasible concept design that meets requirements (Assessment: homework, design reviews, presentations, reporting, prototype performance).
2. Students work as a member of an Integrated Product Team (IPT) to identify and solve design and implementation problems. (Assessment: design reviews, presentations, reporting, prototype performance).
3. Students collect or generate data and develop presentations and reports that fully describe and illustrate the conceptual design and its performance characteristics and capabilities. (Assessment: presentations, reporting).
4. Students document the socio-economic impacts of their design on the discipline, environment, and society (Assessment: presentations, reporting).
5. Students document how this course shaped their understanding of the discipline and its effects on their current and future learning. (Assessment: reflective essay).

STUDENT PROGRAM OUTCOMES (SPOs)

	CLOs				
	1	2	3	4	5
ABET Engineering Student Outcomes. Upon completion, graduates will have demonstrated					
(E1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	•		•		
(E2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	•			•	
(E3) an ability to communicate effectively with a range of audiences	•	•	•	•	•
(E4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	•		•	•	•
(E5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	•	•			•
(E6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	•		•	•	
(E7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	•		•		•

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Course Structure

Monday, Wednesday will be a traditional lecture. PDFs of the PowerPoint files will be available to class after the lecture is completed. Homework assignments will also be announced. It is expected that you do the assigned reading and begin working the homework assignment so that you can make the most of the recitation sessions.

It is important to come prepared and be ready to ask questions. If there are no questions, **quizzes will be** used to assess level of understanding.

Grading

Quizzes	10 %
Homework	10%
Exam 1	20 %
Exam 2	20%
Final Exam	30 %
Attendance, Class Participation Instructor concession	0-10%
Total =	100 %

Grading Scale:

A	90-100 %
A-	88-89.9 %
B+	86-87.9 %
B	83-85.9 %
B-	80-82.9 %
C+	76-79.9 %
C	70-75 %
C-	68-69.9 %
D+	66-67.9 %
D	60-65.9 %

Note: *Letter grades can be adjusted by the instructor which will include modifications to the above indicated scale if the class performance calls for such action.*

COURSE OUTLINE

The course outline is subject to change throughout the semester.

Homework Assignments Summary

Homework has two purposes:

1. To provide the student with timely exercise in the use of the models developed in the lectures.
2. To extend the logic in directions of importance that cannot be covered within the time constraints of the lectures.
3. The problem sets must, therefore, represent your own work. You may discuss the sets with your fellow students but the engineering should be your own.

Course Outline

I.	Introduction to Thermodynamics
II	Heat and Work
III	Property Evaluation
IV	1^{st} Law of Thermodynamics
V	2^{nd} Law of Thermodynamics
VI	Introduction to Heat Transfer
VII	Conduction
VII	Convection
VIII	Radiation
IX	Heat Exchangers

First Law of thermodynamics: First law of thermodynamics, systems, open and closed systems, the steady flow energy equation, Applications of the non-flow and steady flow energy equations to evaluate heat and work interactions in heaters, compressors and fans, turbines and throttling valves etc...
Second Law of thermodynamics: Reversible and Irreversible process, Carnot cycle, thermodynamic heat engines, refrigerators and heat pumps. Examine Carnot Cycle, determination of thermal efficiency for heat engine, refrigerator and heat pumps.
Properties of pure substances: Introduce the concept of a pure substance, use of property tables for determining thermodynamic properties; illustrate the P-v, T-s and P-T property diagram and P-v-T surfaces of pure substances, the ideal-gas equation of state.

Because of the time limits of a single-semester subject, some topics are touched upon with less emphasis. These topics are decided by the instructor based on the lecture progress during the semester.

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1. To provide the student with timely exercise in the use of the models developed in the lectures.
2. To extend the logic in directions of importance that cannot be covered within the time constraints of the lectures.
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Problems Assignments Summary

Problems Designated by a “C”. Are conceptual problems, students are encouraged to do them.

Problems Designated by “E” are in English Units.

Problems Designated with a laptop require a software to be solved.

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Problems Assignments Summary

Problems Designated by a “C”. Are conceptual problems, students are encouraged to do them.

Problems Designated by “E” are in English Units.

Problems Designated with a laptop require a software to be solved.

Chap 1. Problems: 1-1C through 1-11C (conceptual problems, Students are encouraged to do)

Chap 1. Problems; 1-12, 1-13, 1-14, 1-15E, 1-16, 1-18, 1-19, 1-20.

Chap 2. Problems 2.3, 2.4, 2.5, 2.9, 2.12, 2.14, 2.17, 2.18, 2.19, 2.26, 2.38, 2.29, 2.33, 2.35, 2.36, 2.39, 2.41, 2.45, 2.47, 2.62, 2.65, 2.84

Chap 3. Problems; 3.1, 3.2, 3.3, 3.4, 3.6, 3.8, 3.10, 3.12, 3.14, 3.16, 3.18, 3.20, 3.29,3.32, 3.38, 3.42, 3.45,3.54, 3.68, 3.84

Chap 4. Problems; 4.2, 4.4, 4.6, 4.8, 4.10, 4.12, 4.14, 4.16, 4.18, 4.19, 4.20, 4.29, 4.30, 4.34, 4.38, 4.40, 4.42, 4.45, 4.48, 4.49, 4.50, 4.52, 4.62, 4.63

Chap 5. Problems; 5.2, 5.4, 5.6, 5.8, 5.11, 5.19, 5.20, 5.23, 5.33, 5.34, 5.38, 5.63, 5.73, 5.74, 5.96, 5.103

Chap. 6 Problems; 6.7, 6.8, 6.9, 6.12, 6.14, 6.17, 6.26, 6.28, 6.33, 6.35, 6.33, 6.35, 6.40, 6.65, 6.71, 6.72, 6.74,

Chap. 7, 7c, 15, 17E, 19, 22, 23, 26, 40, 43, 47, 53, 68, 78, 88, 91, 93, 97, 100, 114

Chap. 10, 21, 23, 32, 40, 42 44E, 45, 48, 51, 57

Chap. 11, 11E, 15, 18E, 20, 21, 24, 31, 33, 36, 40, 52

Chap. 12, 12, 15, 16, 17, 25, 29, 33, 36, 68, 74, 58

Chap. 16, 21, 22, 29, 33, 35, 36, 39, 40, 47, 52, 60, 61, 62, 64, 66, 79, 82

Chap. 17, 17E, 21, 23, 28, 32, 35E, 75

Course Topics:

week	Days	Topic
1	Aug. 21, 23	Introduction And Overview Ch1
		Thermodynamics
2	August 28, 30	Basic Concepts of Thermodynamics Ch.1, Ch. 2
	Sept. 4 Labor Day	No Classes
3	Sept. 6, 11	Energy, Energy Transfer, And General Energy Analysis, Ch.2, Ch.3
4	Sept.13, 18	Energy Transfer, Properties of Pure Substances Ch. 2, Ch.3, Ch.4
5, 6	Sept. 20, 25	Energy Analysis of Closed Systems Ch. 5,
6	Sep. 27	Energy Analysis of Closed Systems Ch. 5, Ch. 6
7	Oct. 2, 4	Energy Analysis of Closed Systems Ch. 5, Ch. 6
7	Oct. 4	***Midterm exam I, Wednesday***
7	Oct. 5-8	Fall Break
8	Oct. 11, 16	Mass and Energy Analysis Of Control Volumes Ch. 6, Ch 7
9		Fluids Mechanics
9, 10	Oct. 18, 23	Introduction and Properties Of Fluids Ch. 10
10	Oct. 25, 30	Fluid Statics Ch. 11
11	Nov. 1, 6	Bernoulli And Energy Equations …. Ch.12
12	Nov. 8, 13	Momentum Analysis of Flow Systems Ch.12, Chap. 13
13		Heat Transfer
13	Nov 15	Mechanism of Heat Transfer, Ch. 16
13	Nov. 20 (Monday)	***Midterm Exam II, Monday***
14	Nov. 22-Nov 26	Thanksgiving Recess
15	Nov 27, Dec. 29	Steady State Heat Conduction, Ch. 17, Transient Heat Conduction, Ch. 18, an Overview
15	Dec. 4, 6	Forced and Natural Convection, Ch. 19, Ch. 20/ Review and Discussions

Final Exam Thursday, December 15, 12:45 PM- 3:00 PM

Holidays: Monday; Sept. 4 Labor Day
Friday; Nov. 10 Veterans Day
Thanksgiving Recess Nov 22-Nov 26

Appendix 1
Property Tables and Charts (Si Units) page 969

Appendix 2
Property Tables and Charts (English Units) page 1013Index Page, 1051
Nomenclature, Page 1061
Conversion Factors and Some Physical Constants, Page 1065

Attendance Policy

Attendance will be taken; it is expected that you attend all lectures and recitations. If you have planned absence, please let Dr. Aziz know.

Students with Disabilities:

University policy 3342-3-01.3 requires that students with disabilities be provided reasonable accommodations to ensure their equal access to course content. If you have a documented disability and require accommodations, please contact the instructor at the beginning of the semester to arrange for necessary classroom adjustments. Please note, you must first verify your eligibility for these through Student Accessibility Services (contact 330-672-3391 or visit www.kent.edu/sas for more information on registration procedures).

Class Policies:

- Please be on time to class. Also, please do not leave class unless we are on break or an emergency arises. Students entering and leaving during the class are a distraction.
- Please turn off your cell phone during class. Texting, cell phones ringing, or worse yet, receiving a cell phone call during class is a distraction. Please do not eat during class.

Copyright and Intellectual Property
• NOTICE OF MY COPYRIGHT AND INTELLECTUAL PROPERTY RIGHTS. Any intellectual property displayed or distributed to students during this course (including but not limited to PowerPoint's, notes, quizzes, and examinations) by the professor / lecturer / instructor remains the intellectual property of the professor / lecturer / instructor. This means that the student may not distribute, publish or provide such intellectual property to any other person or entity for any reason, commercial or otherwise, without the express written permission of the professor / lecturer / instructor.
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Please refer to the link below for updates concerning Covid-19 guidelines.

https://www.kent.edu/coronavirus/coronavirus-dashboard

Please refer to the link below for updates concerning Covid-19 guidelines and **Updates**

https://www.kent.edu/coronavirus/coronavirus-dashboard
https://www.kent.edu/coronavirus/flashes-safe-seven#while-on-campus
https://www.kent.edu/coronavirus

KENT STATE'S SAFETY PRINCIPLES

1. ALWAYS WEAR YOUR FACE COVERING
2. WASH YOUR HANDS FREQUENTLY
3. CLEAN AND SANITIZE
4. STAY AT LEAST 6 FEET APART
5. MONITOR YOUR HEALTH EVERY DAY
6. HAVE QUESTIONS? REACH OUT
7. For health questions about COVID-19 and safe practices, call **University Health Services** at 330-672-2326, or after hours, contact the Kent State Nurse Line at 330-672-2326. Also, visit our **COVID-19 website** for more information.

Chapter 1

Introduction And Overview

Objectives

- Be acquainted with the engineering sciences thermodynamics, heat transfer, and fluid mechanics, and understand the basic concepts of thermal-fluid sciences.
- Be comfortable with the metric SI and English units commonly used in engineering.
- Develop an intuitive systematic problem-solving technique.
- Learn the proper use of software packages in engineering if applicable.
- Develop an understanding of accuracy and significant digits in calculations.

1-1 INTRODUCTION TO THERMAL-FLUID SCIENCES

- **Thermal-fluid sciences: The physical sciences that deal with energy and the transfer, transport, and conversion of energy.**
- **Thermal-fluid sciences are studied under the subcategories of**
  - thermodynamics
  - heat transfer
  - fluid mechanics

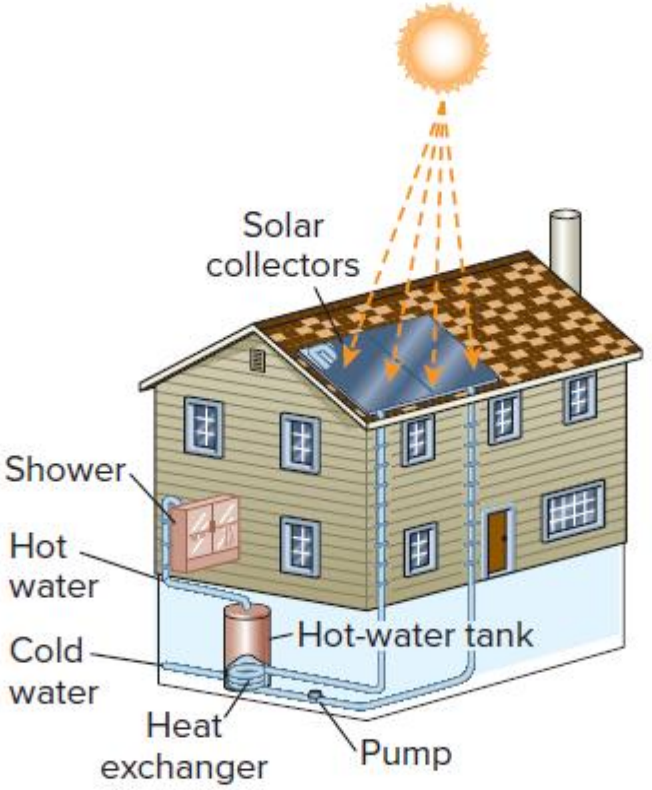

FIGURE 1–1
The design of many engineering systems, such as this solar hot-water system, involves thermal-fluid sciences.

Application Areas of Thermal-Fluids Sciences

Refrigerator

© McGraw-Hill Education/Jill Braaten, photographer

Boats

© Doug Menuez/Getty Images RF

Aircraft and spacecraft

© PhotoLink/Getty Images RF

Power plants

© Malcolm Fife/Getty Images RF

Human body

© Ryan McVay/Getty Images RF

Cars

© Mark Evans/Getty Images RF

Wind turbines

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Food processing

Glow Images RF

A piping network in an industrial facility

Courtesy of UMDE Engineering Contracting and Trading. Used by permission

1-2 THERMODYNAMICS

- **Thermodynamics:** The science of *energy.*
- **Energy:** The ability to cause changes.
- The name *thermodynamics* stems from the Greek words *therme* (heat and *dynamis* (power).
- **Conservation of energy principle:** During an interaction, energy can change from one form to another, but the total amount of energy remains constant.

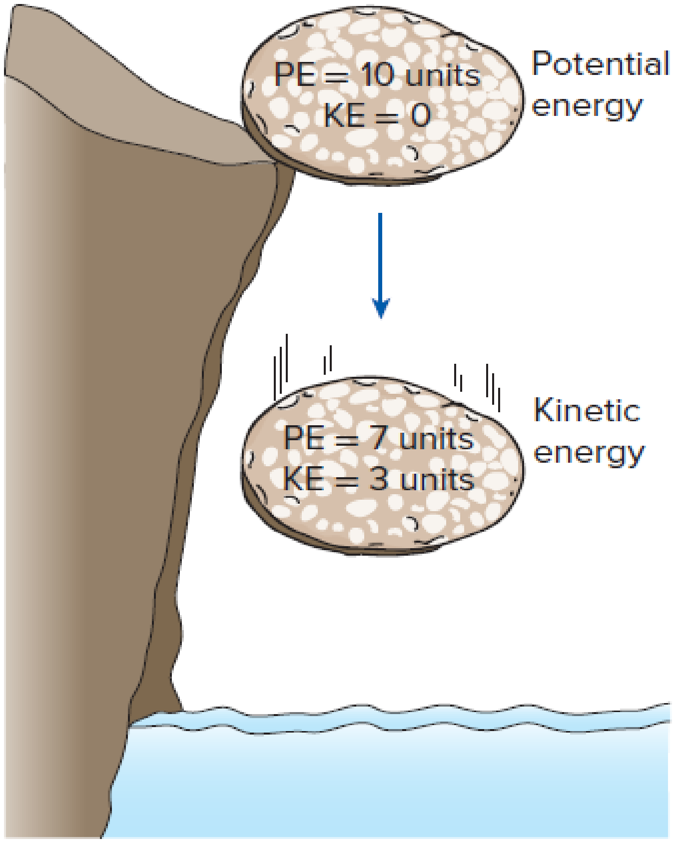

FIGURE 1–3
Energy cannot be created or destroyed; it can only change forms (the first law).

The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (power), which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations including power generation, refrigeration, and relationships among the properties of matter.

1-2 THERMODYNAMICS

- **Energy cannot be created or destroyed.**
- **The first law of thermodynamics: An expression of the conservation of energy principle.**
- **The first law asserts that *energy* is a thermodynamic property.**

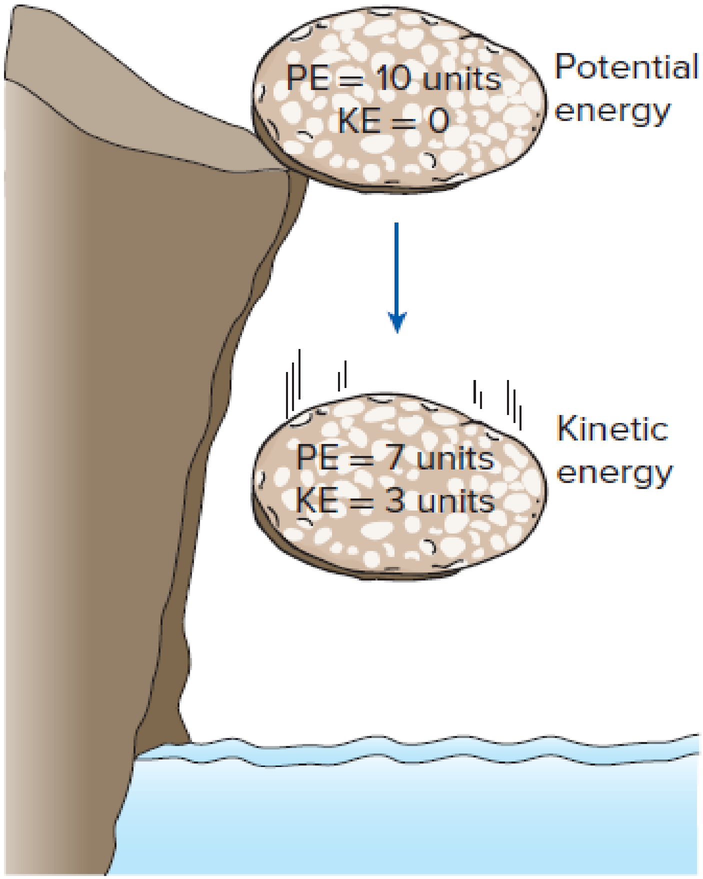

FIGURE 1–3
Energy cannot be created or destroyed; it can only change forms (the first law).

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1-2 THERMODYNAMICS-1

- **The second law of thermodynamics:** It asserts that energy has ***quality*** as well as ***quantity***, and actual processes occur in the direction of decreasing quality of energy.
- **Classical thermodynamics:** A **macroscopic approach** to the study of thermodynamics that does not require a knowledge of the behavior of individual particles.
- It provides a direct and easy way to the solution of engineering problems.

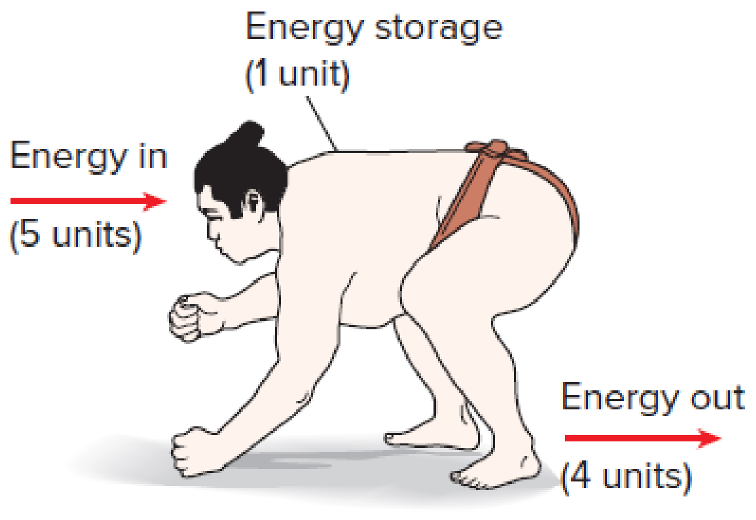


FIGURE 1–4
Conservation of energy principle for the human body.

1-2 THERMODYNAMICS-1

- **Statistical thermodynamics:** **A microscopic approach, based on the average behavior of large groups of individual particles.**

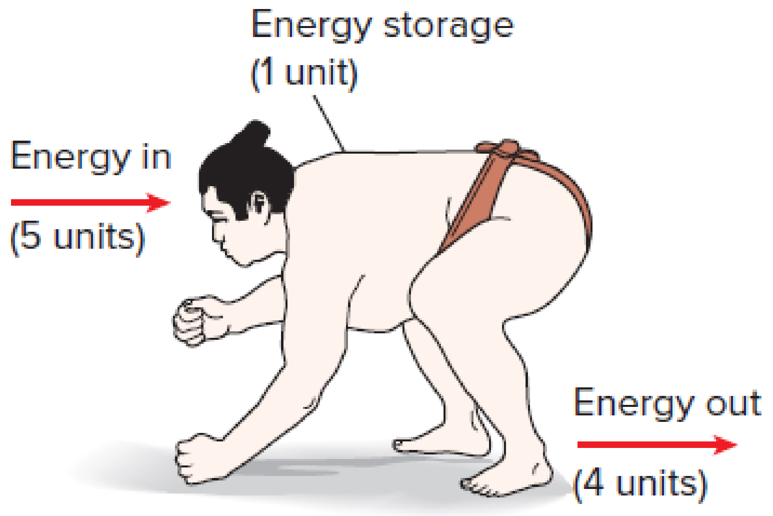


FIGURE 1–4
Conservation of energy principle for the human body.

1-3 HEAT TRANSFER

- **Heat:** The form of energy that can be transferred from one system to another as a result of temperature difference.
- **Heat Transfer:** The science that deals with the determination of the rates of such energy transfers and variation of temperature.

1-3 HEAT TRANSFER

- *Thermodynamics* is concerned with the *amount* of heat transfer as a system undergoes a process from one equilibrium state to another, and it gives no indication about *how long* the process will take. But in engineering, we are often interested in the *rate* of heat transfer, which is the topic of the science of ***heat transfer.***

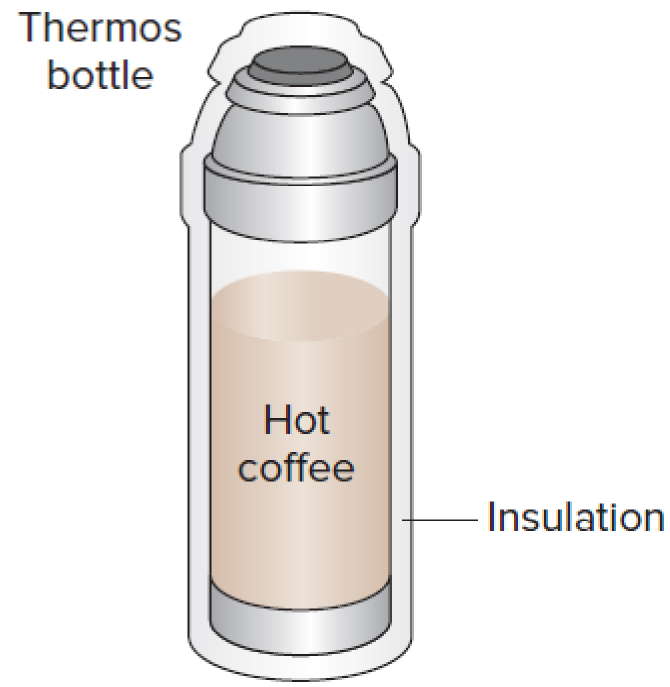


FIGURE 1–5
We are normally interested in how long it takes for the hot coffee in a thermos bottle to cool to a certain temperature, which cannot be determined from a thermodynamic analysis alone.

1-3 HEAT TRANSFER-1

The *first law requires that the rate of energy transfer into a system be equal to the rate of increase of the energy of that system.*

The second law requires that heat be transferred in the direction of decreasing temperature.

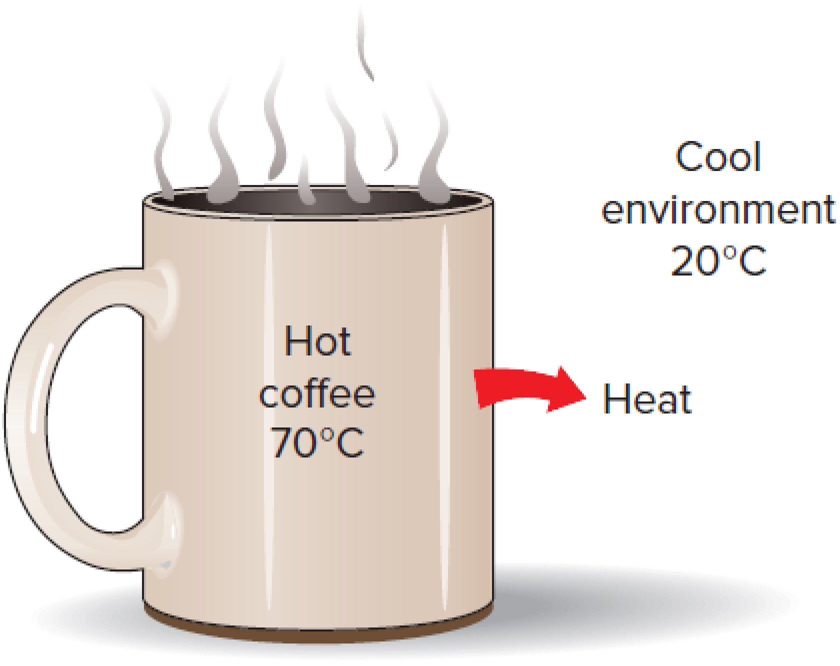


FIGURE 1–6
Heat flows in the direction of decreasing temperature.

1-2 THERMODYNAMICS-1

- For example, a cup of hot coffee left on a table eventually cools, but a cup of cool coffee in the same room never gets hot by itself.
- The high-temperature energy of the coffee is degraded (transformed into a less useful form at a lower temperature) once it is transferred to the surrounding air.

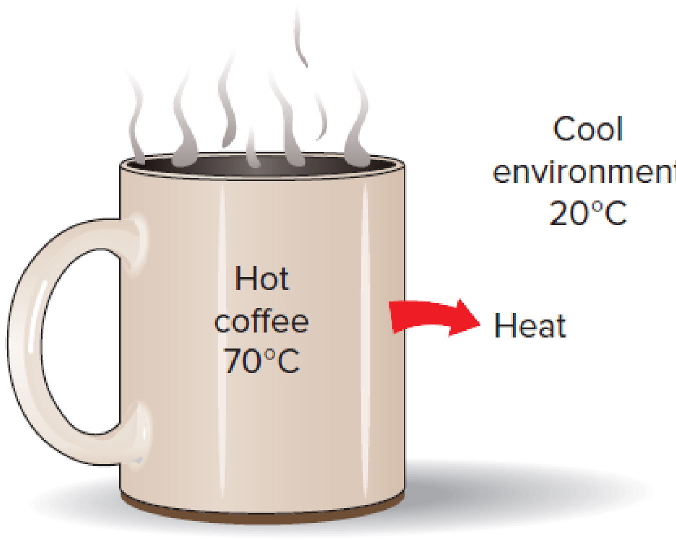


FIGURE 1–6
Heat flows in the direction of decreasing temperature.

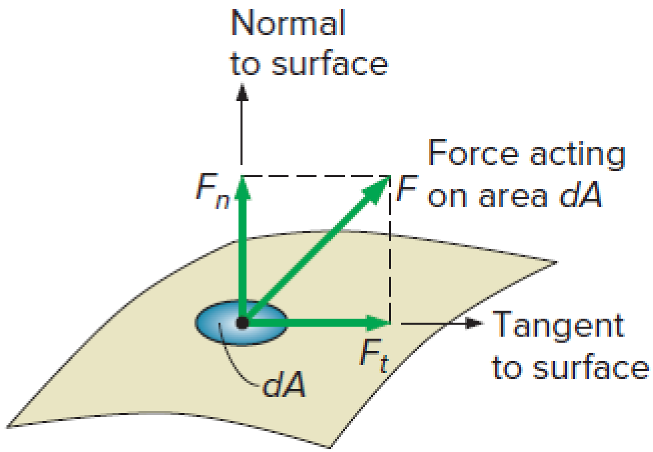
Fluid mechanics itself is also divided into several categories.

- **The study of the motion of fluids that can be approximated as incompressible (such as liquids, especially water, and gases at low speeds) is usually referred to as hydrodynamics.**
- **A subcategory of hydrodynamics is hydraulics, which deals with liquid flows in pipes and open channels.**

1-4 FLUID MECHANICS-1

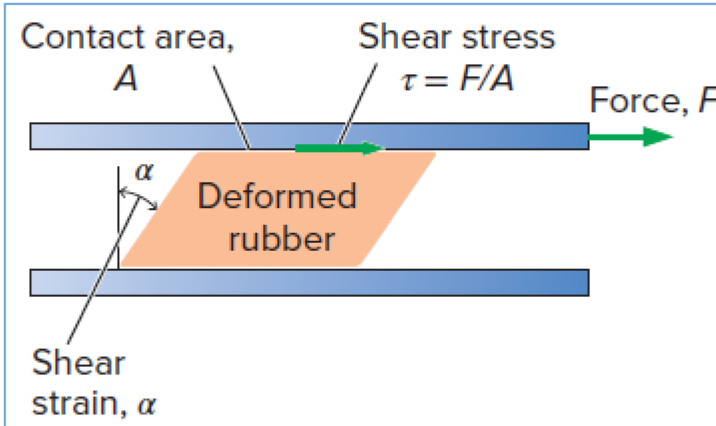
- **Gas dynamics** deals with the flow of fluids that undergo significant density changes, such as the flow of gases through nozzles at high speeds.
- The category **aerodynamics** deals with the flow of gases (especially air) over bodies such as aircraft, rockets, and automobiles at high or low speeds.
- Some other specialized categories such as **meteorology**, **oceanography**, and **hydrology** deal with naturally occurring flows.

1-4 FLUID MECHANICS-2



$$\text{Normal stress: } \sigma = \frac{F_n}{dA}$$

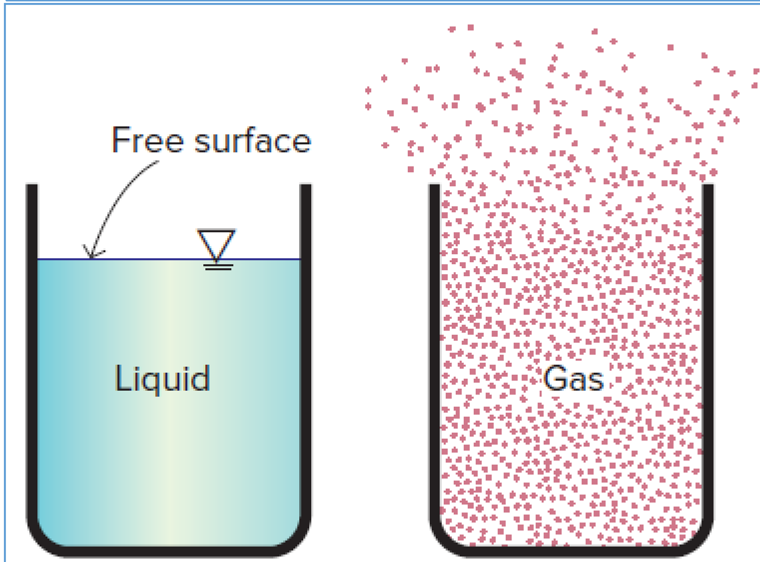
$$\text{Shear stress: } \tau = \frac{F_t}{dA}$$



The normal stress and shear stress at the surface of a fluid element. For fluids at rest, the shear stress is zero and pressure is the only normal stress.

Deformation of a rubber block placed between two parallel plates under the influence of a shear force.

The shear stress shown is that on the rubber—an equal but opposite shear stress acts on the upper plate.



Unlike a liquid, a gas does not form a free surface, and it expands to fill the entire available space.

Laws of Thermodynamics

- **0th law:** If two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other
- **1st law:** Energy can neither be created nor destroyed. It can only change forms
- **2nd law:** Processes will occur naturally in the direction of decreasing quality of energy
- **3rd law:** As temperature approaches absolute zero, the entropy of a system approaches a constant minimum

Why is it called the Zeroth Law of Thermodynamics?

It is called the "**zeroth**" **law** because it came to light after the first and second **laws of thermodynamics** had already been established and **named** but was considered more fundamental and thus was given a lower number — zero.

The **three laws of thermodynamics** define physical quantities (temperature, energy, and entropy) that characterize **thermodynamic** systems at thermal equilibrium. ...

Third **law of thermodynamics**: The entropy of a system approaches a constant value as the temperature approaches absolute zero.

Entropy is a property of state. Thus, the change in entropy ΔS of a system between state 1 and state 2 is the same no matter how the change occurs.
Entropy is an energy divided by a temperature,

Enthalpy (H) is the heat content of a system at constant pressure

Definitions

- Closed System
- Open System
- Steady Flow
- Unsteady Flow
- Uniform Flow
- Boundary
- Surroundings
- Intensive
- Extensive
- Internal Energy
- Enthalpy
- Specific Heat
- Entropy
- Boundary Work
- Flow energy

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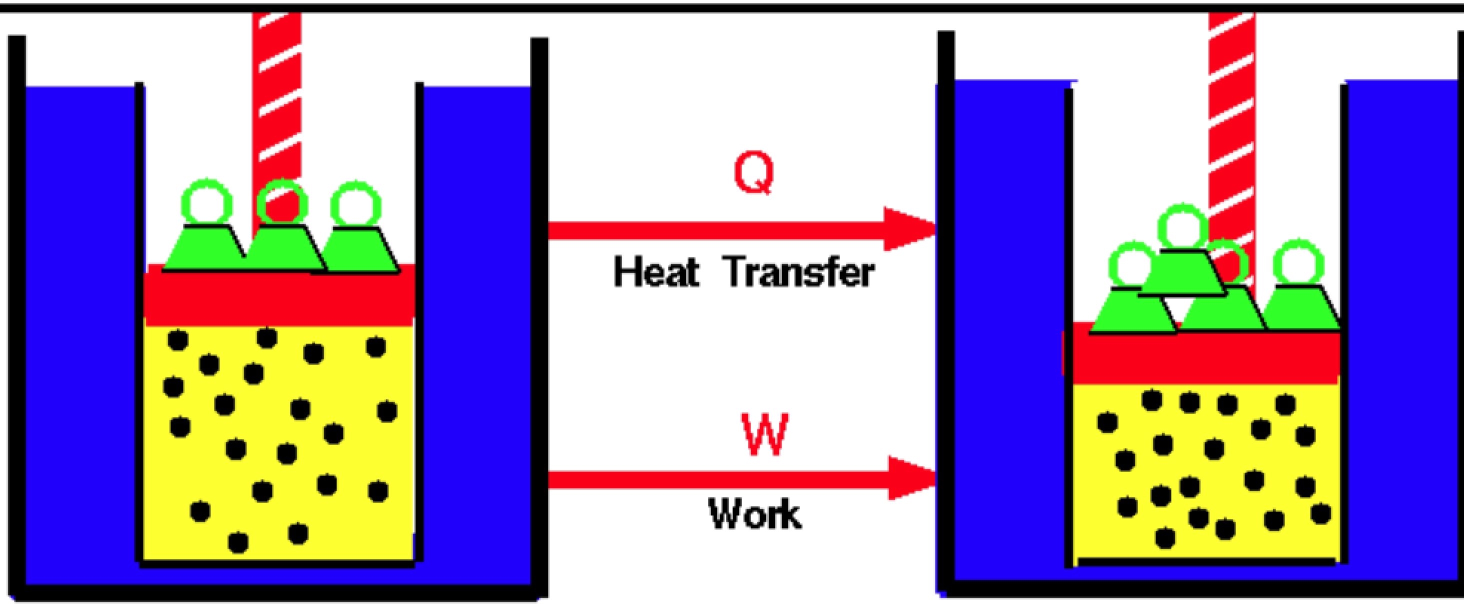
First Law of Thermodynamics

Glenn Research Center



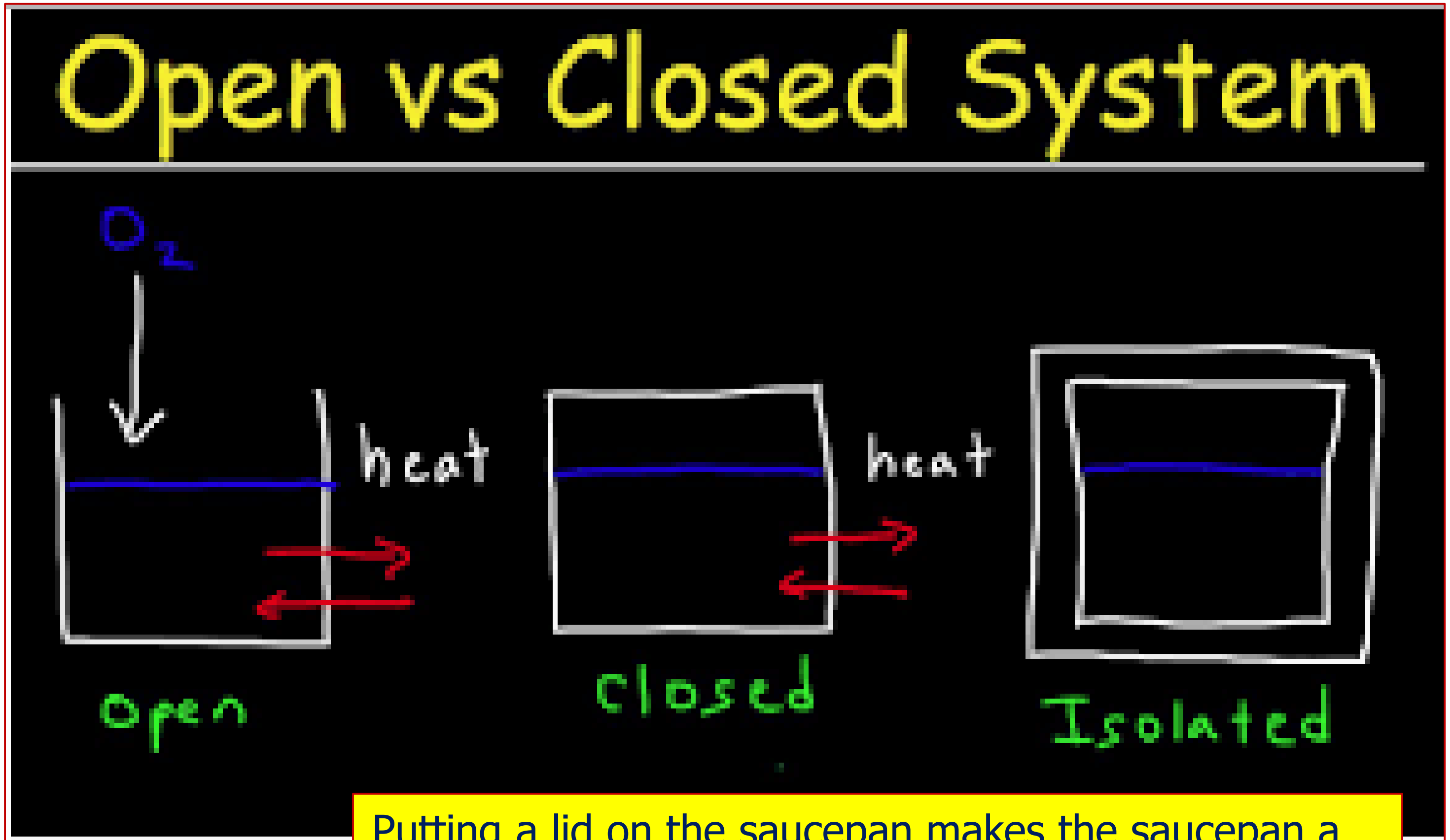
State 1

State 2

E = Internal Energy

$$E_2 - E_1 = Q - W$$

Any thermodynamic system in an equilibrium state possesses a state variable called the internal energy (E). Between any two equilibrium states, the change in internal energy is equal to the difference of the heat transfer into the system and work done by the system.



An **isolated system does not exchange energy or matter** with its surroundings.

For example, if soup is poured into an insulated container (as seen in the figure shown) and closed, there is no exchange of heat or matter.

open system is a system that freely exchanges *energy* and *matter* with its surroundings.

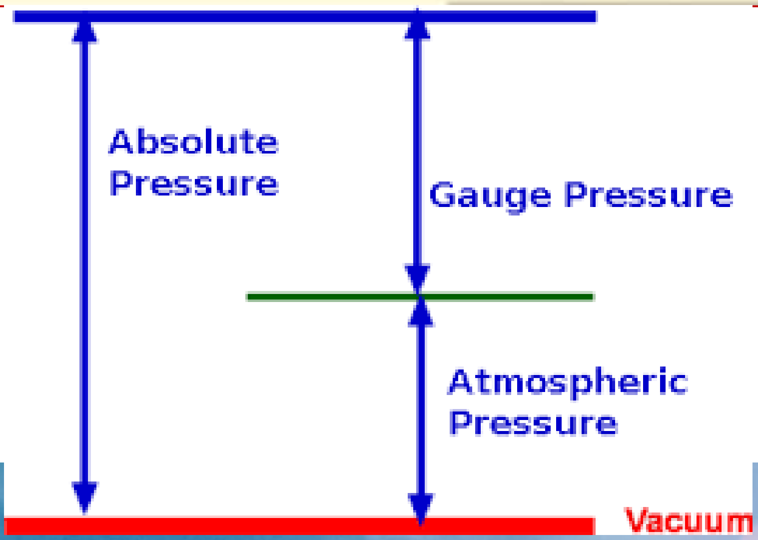
For instance, when you are boiling soup in an open saucepan on a stove, energy and matter are being transferred to the surroundings through steam.

Putting a lid on the saucepan makes the saucepan a closed system.

A **closed system** is a system that exchanges **only energy** with its surroundings, not matter. By putting a lid on the saucepan, matter can no longer transfer because the lid prevents matter from entering the saucepan and leaving the saucepan. Still, the saucepan allows energy transfer.

Pressure

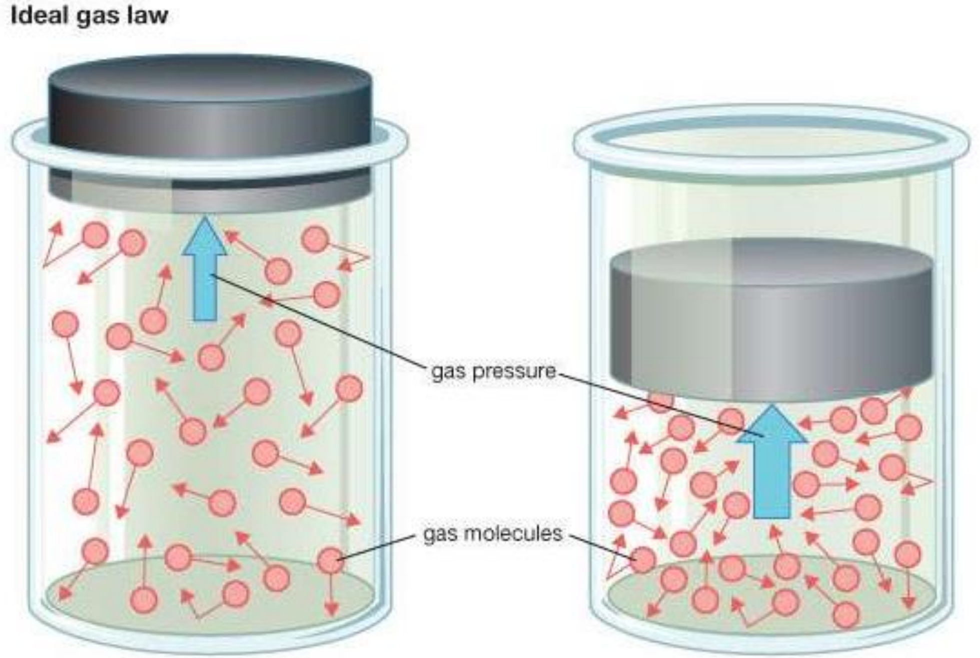
- **Absolute Pressure**—the actual pressure at a given position
- **Gage pressure**—The difference between actual pressure and local atmospheric pressure
- **Vacuum pressure**—Used when actual pressure is less than atmospheric (negative gage pressure)



ideal gas law

ccording to the ideal gas law, when a gas is compressed into a smaller volume, the number and velocity of molecular collisions increase, raising the gas's temperature and pressure.

Encyclopædia Britannica, Inc.



The pressure exerted by a confined gas results from the average effect of the forces produced on the container walls by the rapid and continual bombardment of the huge number of gas molecules. Absolute pressure of a gas or liquid is the total pressure it exerts, including the effect of atmospheric pressure. An absolute pressure of zero corresponds to empty space or a complete vacuum.

The Ideal Gas Law is simply the combination of all Simple Gas Laws

(Boyle's Law,

$$P \propto \frac{1}{V}$$

$$P_1 V_1 = P_2 V_2$$

expressed from two pressure/volume points

Charles' Law,

$$V \propto T$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

expressed from two volume/temperature points

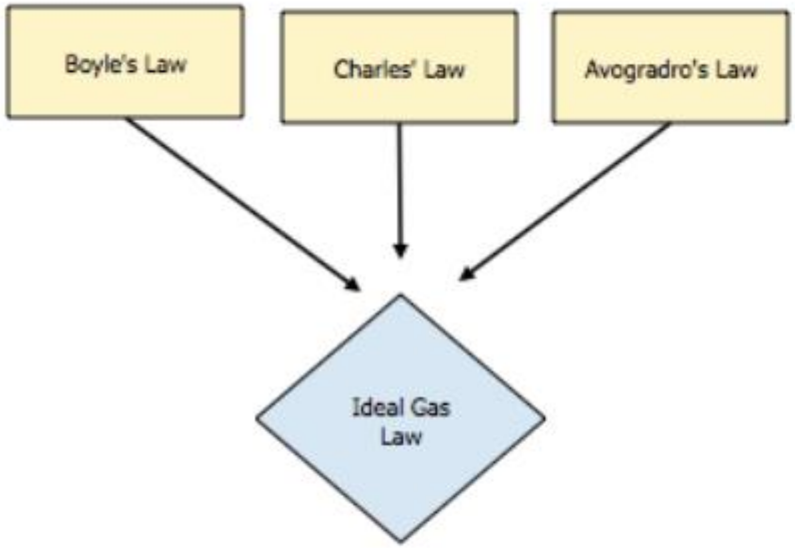
and Avogadro's Law),

$$V \propto n$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

expressed as a two volume/number points:

Ideal Gas Law



the **Ideal Gas Equation**

The four gas variables are: *pressure* (P), *volume* (V), *number of mole of gas* (n), and *temperature* (T). Lastly, the constant in the equation shown below is R, known as the *gas constant*,

$$PV = nRT$$

1-5 IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units.**
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while others such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or **derived dimensions**.
- **Metric SI system:** A simple and logical system based on a decimal relationship between the various units.
- **English system:** It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

1-5 IMPORTANCE OF DIMENSIONS AND UNITS-1

TABLE 1-1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

TABLE 1-2

Standard prefixes in SI units

Multip9le	Prefix
10^{24}	yotta, Y
10^{21}	zetta, Z
10^{18}	exa, E
10^{15}	peta, P
10^{12}	tera, T
10^{9}	giga, G
10^{6}	mega, M
10^{3}	kilo, k
10^{2}	hecto, h
10^{1}	deka, da
10^{-1}	deci, d
10^{-2}	centi, c
10^{-3}	milli, m
10^{-6}	micro, μ
10^{-9}	nano, n
10^{-12}	pico, p
10^{-15}	femto, f
10^{-18}	atto, a
10^{-21}	zepto, z
10^{-24}	yocto, y

SI and English Units

$$1 \text{ lbm} = 0.45359 \text{ kg}$$
$$1 \text{ ft} = 0.3048 \text{ m}$$

$$\text{Force} = (\text{Mass})(\text{Acceleration})$$

$$F = ma$$

$$1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$$

$$1 \text{ lbf} = 32.174 \text{ lbm} \cdot \text{ft/s}^2$$

$$\text{Work} = \text{Force} \times \text{Distance}$$
$$1 \text{ J} = 1 \text{ N} \cdot \text{m}$$
$$1 \text{ cal} = 4.1868 \text{ J}$$
$$1 \text{ Btu} = 1.0551 \text{ kJ}$$

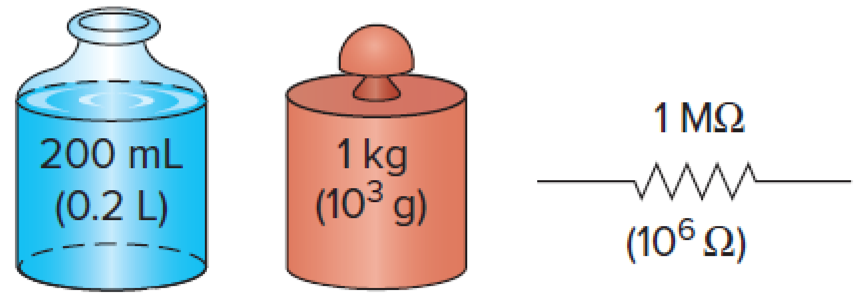


FIGURE 1–11
The SI unit prefixes are used in all branches of engineering.

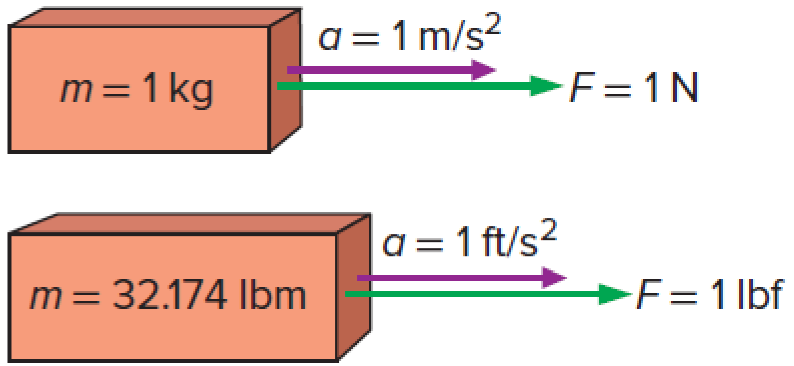


FIGURE 1–12
The definition of the force units.

SI and English Units-1

FIGURE 1–14
A body weighing 150 lbf on earth will weigh only 25 lbf on the moon.

- The mass of a body remains the same regardless of its location in the universe. Its weight, however, changes with a change in gravitational acceleration.

- A body weighs less on top of a mountain since g decreases with altitude. On the surface of the moon, an astronaut weighs about one- sixth of what she or he normally weighs on earth (Fig. 1–14)

$$W = mg \qquad \text{(N)}$$

W weight
m mass
g gravitational acceleration

SI and English Units-1

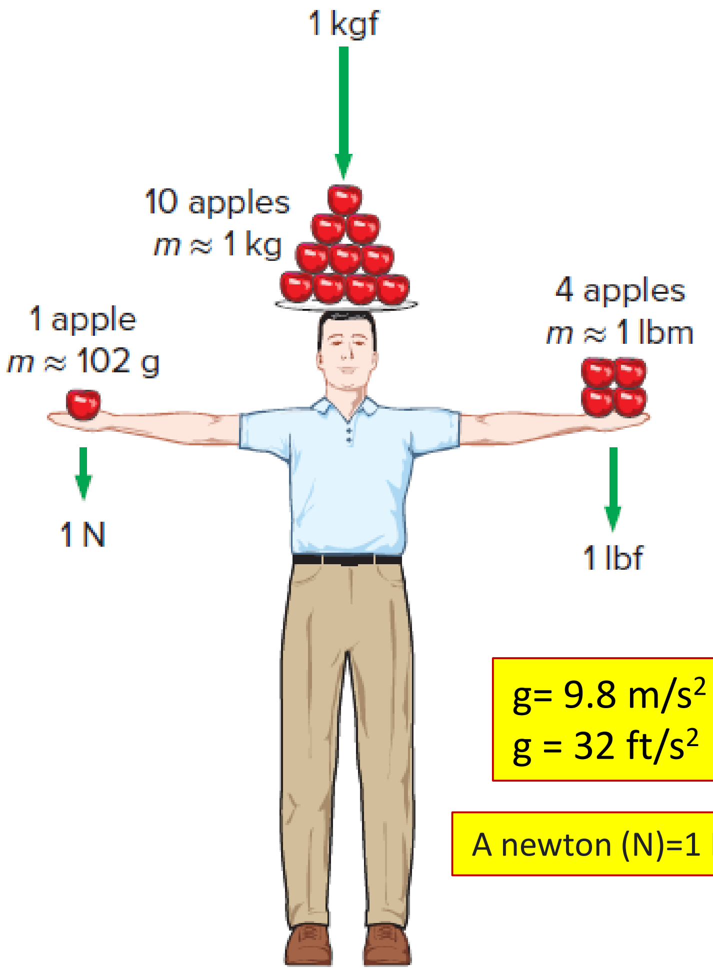


FIGURE 1–13
The relative magnitudes of the force units newton (N), kilogram-force (kgf), and pound-force (lbf).

g= 9.8 m/s^2
g = 32 ft/s^2

A newton (N)=1 Kg m/s^2

The term weight is often incorrectly used to express mass, particularly by the "weight watchers." Unlike mass, weight W is a force. It is the gravitational force applied to a body, and its magnitude is determined from Newton's second law,

$$W = mg \qquad (\mathrm{N})$$

W weight
m mass
g gravitational acceleration

Some SI and English Units-2

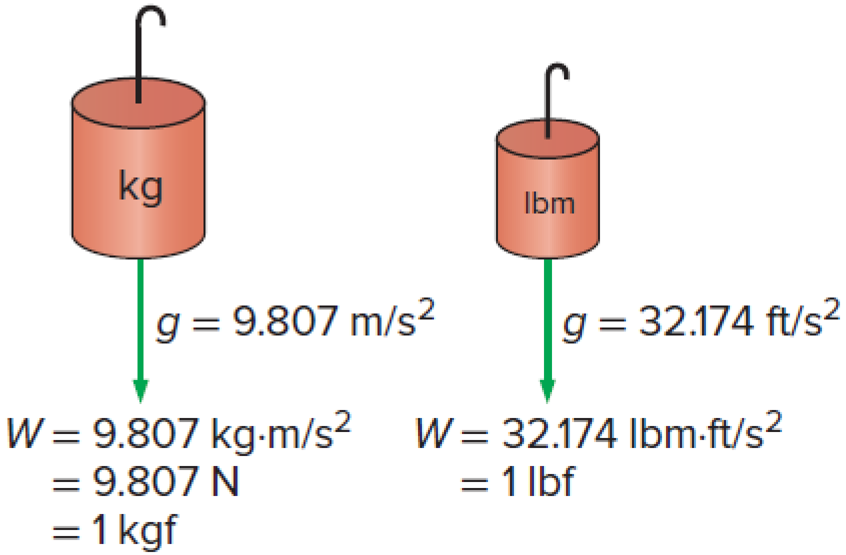


FIGURE 1–15
The weight of a unit mass at sea level.

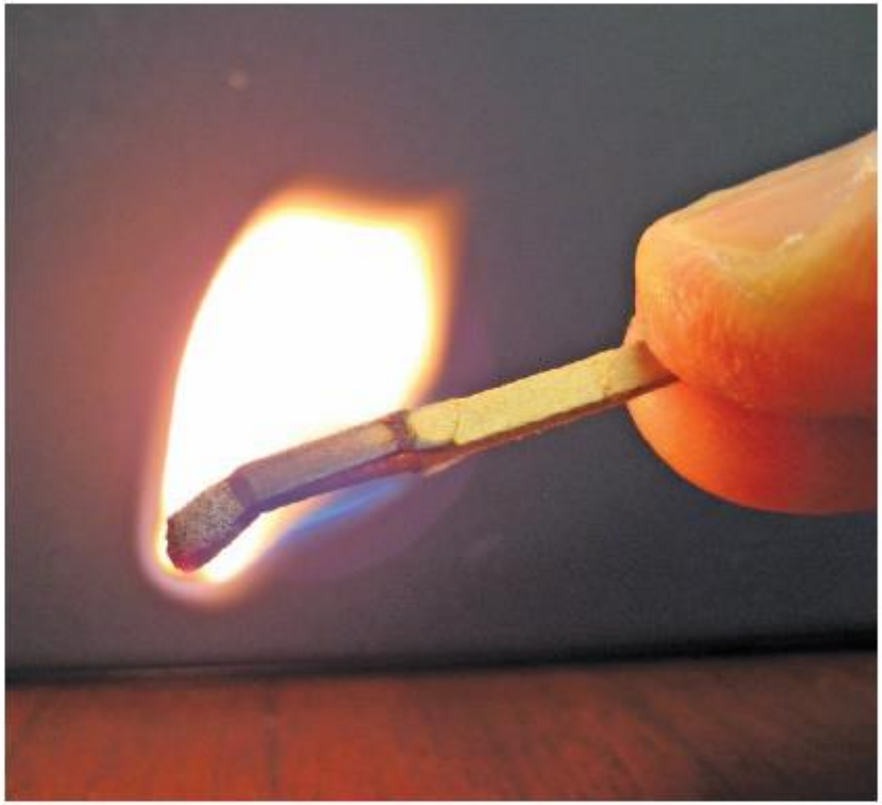


FIGURE 1–16
A typical match yields about 1 Btu (or 1 kJ) of energy if completely burned.

Specific weight γ: The weight of a unit volume of a substance.

$$\gamma = \rho g$$

Dimensional homogeneity

All equations must be dimensionally similar.

Unity Conversion Ratios

***All non-primary units (secondary units) can be formed by combinations of primary units*.**
Force units, for example, can be expressed as

$$\mathrm{N} = \mathrm{kg}\,\frac{\mathrm{m}}{\mathrm{s}^2} \quad \textbf{and} \quad \mathrm{lbf} = 32.174\ \mathrm{lbm}\,\frac{\mathrm{ft}}{\mathrm{s}^2}$$

They can also be expressed more conveniently as unity conversion ratios as

$$\frac{\mathrm{N}}{\mathrm{kg{\cdot}m/s^2}} = 1 \quad \textbf{and} \quad \frac{\mathrm{lbf}}{32.174\ \mathrm{lbm{\cdot}ft/s^2}} = 1$$

Unity conversion ratios are identically equal to 1 and are unitless, and thus such ratios (or their inverses) can be inserted conveniently into any calculation to properly convert units.

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EXAMPLE 1–1 **Electric Power Generation by a Wind Turbine**

A school is paying \$0.12/kWh for electric power. To reduce its power bill, the school installs a wind turbine (Fig. 1–17) with a rated power of 30 kW. If the turbine operates 2200 hours per year at the rated power, determine the amount of electric power generated by the wind turbine and the money saved by the school per year.

FIGURE 1–17

A wind turbine, as discussed in **Example 1–1**.

SOLUTION

A wind turbine is installed to generate electricity. The amount of electric energy generated and the money saved per year are to be determined.

Analysis

The wind turbine generates electric energy at a rate of 30 kW or 30 kJ/s. Then the total amount of electric energy generated per year becomes

$$\begin{aligned}\text{Total energy} &= (\text{Energy per unit time})(\text{Time interval})\\ &= (30\ \text{kW})(2200\ \text{h})\\ &= \mathbf{66{,}000\ kWh}\end{aligned}$$

The money saved per year is the monetary value of this energy determined as

$$\begin{aligned}\text{Money saved} &= (\text{Total energy})(\text{Unit cost of energy})\\ &= (66{,}000\ \text{kWh})(\$0.12/\text{kWh})\\ &= \mathbf{\$7920}\end{aligned}$$

Discussion

The annual electric energy production also could be determined in kJ by unit manipulations as

$$\text{Total energy} = (30\ \text{kW})(2200\ \text{h})\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)\left(\frac{1\ \text{kJ/s}}{1\ \text{kW}}\right) = 2.38 \times 10^8\ \text{kJ}$$

which is equivalent to 66,000 kWh (1 kWh = 3600 kJ).

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EXAMPLE 1–2 **Obtaining Formulas from Unit Considerations**

A tank is filled with oil whose density is $\rho = 850$ kg/m^3. If the volume of the tank is $V = 2$ m^3, determine the amount of mass m in the tank.

SOLUTION

The volume of an oil tank is given. The mass of oil is to be determined.

Assumptions

Oil is a nearly incompressible substance and thus its density is constant.

Analysis

A sketch of the system just described is given in Fig. 1–18. Suppose we forgot the formula that relates mass to density and volume. However, we know that mass has the unit of kilograms. That is, whatever calculations we do, we should end up with the unit of kilograms. Putting the given information into perspective, we have

$$\rho = 850 \text{ kg/m}^3 \quad \text{and} \quad V = 2 \text{ m}^3$$

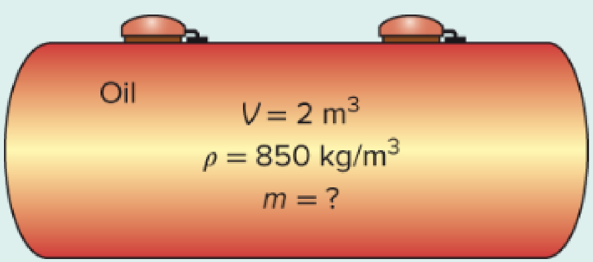


FIGURE 1–18
Schematic for Example 1–2.

It is obvious that we can eliminate m^3 and end up with kg by multiplying these two quantities. Therefore, the formula we are looking for should be

$$m = \rho V$$

Thus,

$$m = (850 \text{ kg/m}^3)(2 \text{ m}^3) = \mathbf{1700\ kg}$$

Discussion

Note that this approach may not work for more complicated formulas. Nondimensional constants also may be present in the formulas, and these cannot be derived from unit considerations alone.

- When you buy a box of breakfast cereal, the printing may say "Net weight: One pound (454 grams)." (See Fig. 1–22.)

- Technically, this means that the cereal inside the box weighs 1.00 lbf on earth and has a mass of 453.6 g (0.4536 kg). Using Newton's second law, the actual weight of the cereal on earth is

FIGURE 1–22

$$W = mg = (453.6\text{ g})(9.81\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1\text{ kg}}{1000\text{ g}}\right) = 4.49\text{ N}$$

Dimensional homogeneity-1

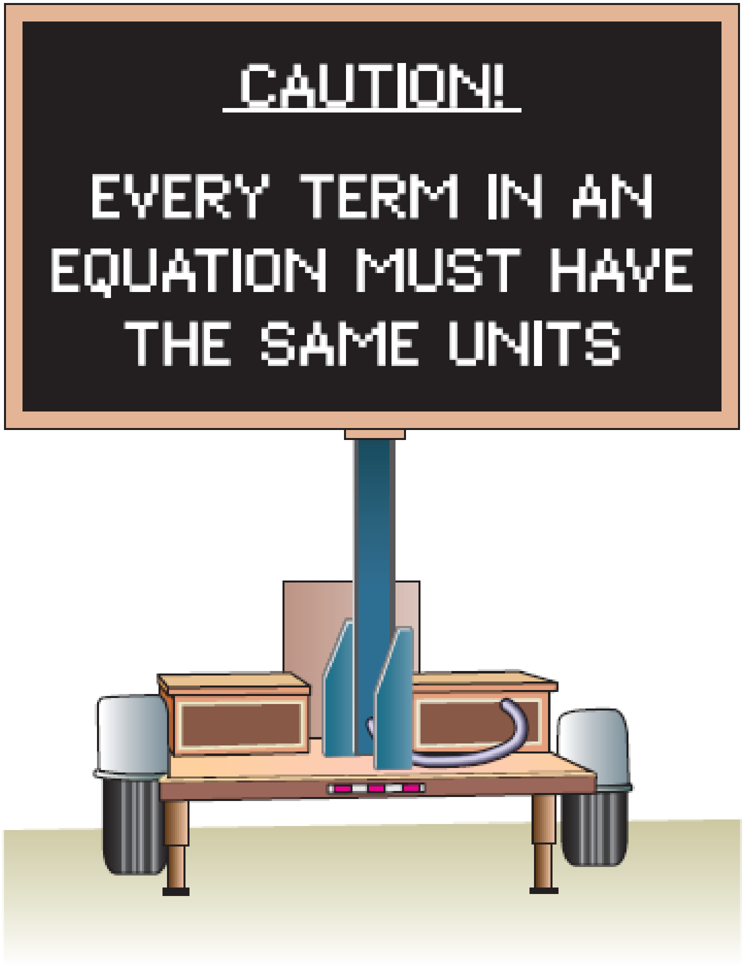


FIGURE 1–19
Always check the units in your calculations.

$$1\ \text{N} = 1\ \text{kg}\ \frac{\text{m}}{\text{s}^2} \qquad \text{and} \qquad 1\ \text{lbf} = 32.174\ \text{lbm}\ \frac{\text{ft}}{\text{s}^2}$$

They can also be expressed more conveniently as **unity conversion ratios** as

$$\frac{1\ \text{N}}{1\ \text{kg·m/s}^2} = 1 \qquad \text{and} \qquad \frac{1\ \text{lbf}}{32.174\ \text{lbm·ft/s}^2} = 1$$

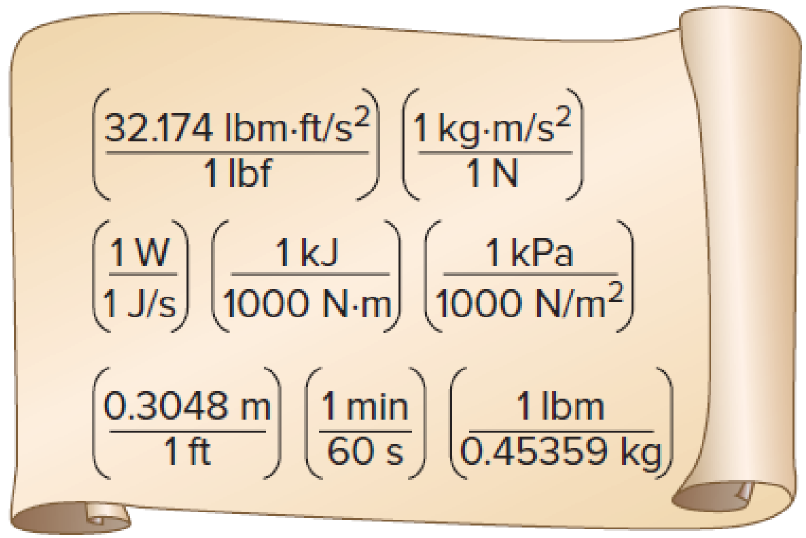


FIGURE 1–20
Every unity conversion ratio (as well as its inverse) is exactly equal to 1. Shown here are a few commonly used unity conversion ratios.

FIGURE 1–21
A mass of 1 lbm weighs 1 lbf on earth.

EXAMPLE 1–3 The Weight of One Pound-Mass

Using unity conversion ratios, show that 1.00 lbm weighs 1.00 lbf on earth (Fig. 1–21).

SOLUTION A mass of 1.00 lbm is subjected to standard earth gravity. Its weight in lbf is to be determined.
Assumptions Standard sea-level conditions are assumed.
Properties The gravitational constant is $g = 32.174\ \text{ft/s}^2$.
Analysis We apply Newton's second law to calculate the weight (force) that corresponds to the known mass and acceleration. The weight of any object is equal to its mass times the local value of gravitational acceleration. Thus,

$$W = mg = (1.00\ \text{lbm})(32.174\ \text{ft/s}^2)\left(\frac{1\ \text{lbf}}{32.174\ \text{lbm}\cdot\text{ft/s}^2}\right) = \mathbf{1.00\ lbf}$$

Discussion The quantity in large parentheses in this equation is a unity conversion ratio. Mass is the same regardless of its location. However, on some other planet with a different value of gravitational acceleration, the weight of

1-6 PROBLEM-SOLVING TECHNIQUE

- Step 1: Problem Statement
- Step 2: Schematic
- Step 3: Assumptions and Approximations
- Step 4: Physical Laws
- Step 5: Properties
- Step 6: Calculations
- Step 7: Reasoning, Verification, and Discussion

1-6 PROBLEM-SOLVING TECHNIQUE-1

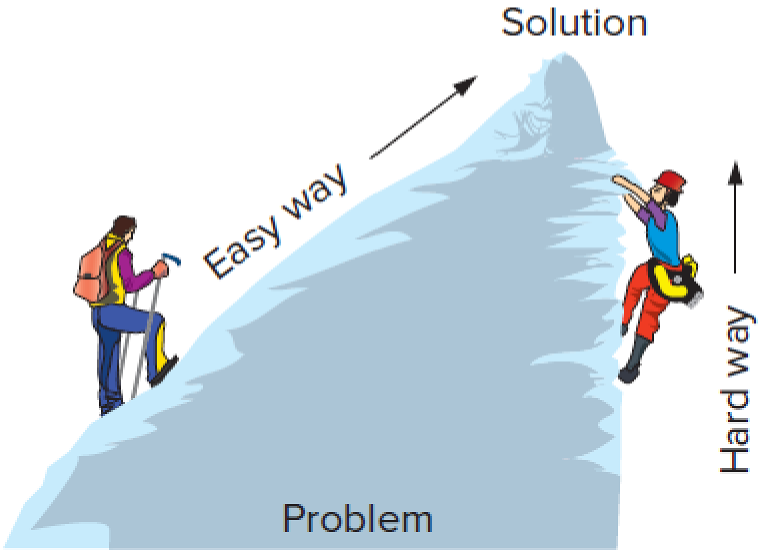
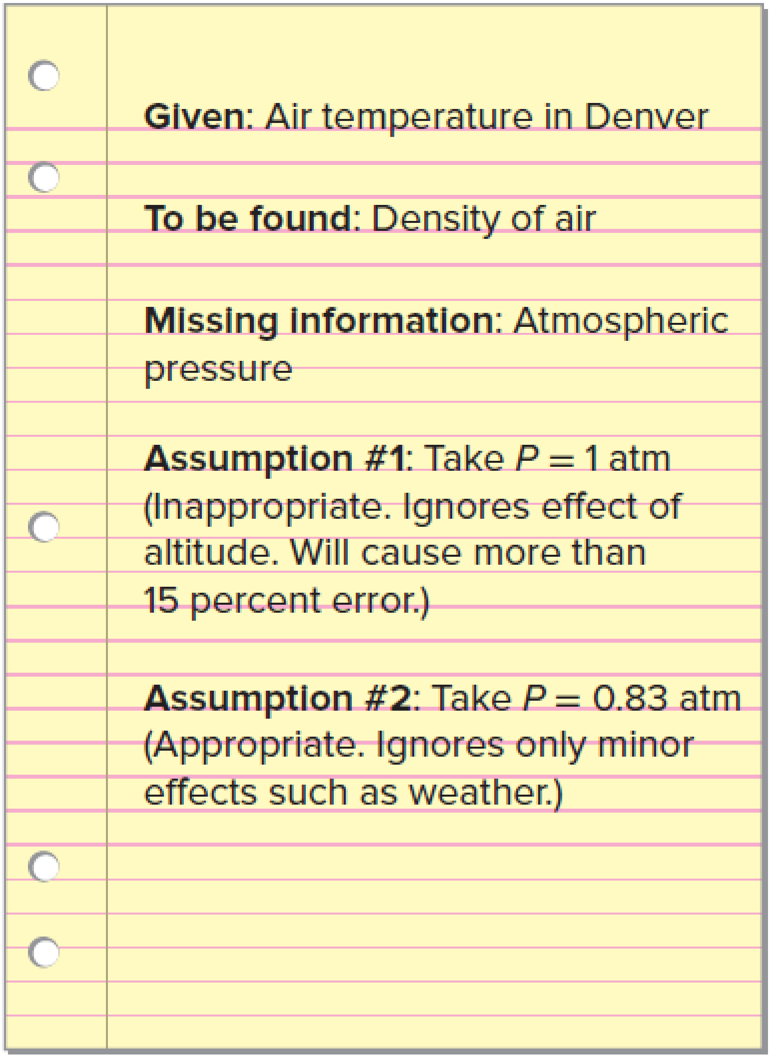


FIGURE 1–23
A step-by-step approach can greatly simplify problem solving.


Given: Air temperature in Denver

To be found: Density of air

Missing information: Atmospheric pressure

Assumption #1: Take $P = 1$ atm (Inappropriate. Ignores effect of altitude. Will cause more than 15 percent error.)

Assumption #2: Take $P = 0.83$ atm (Appropriate. Ignores only minor effects such as weather.)

FIGURE 1–24
The assumptions made while solving an engineering problem must be reasonable and justifiable.

1-6 PROBLEM-SOLVING TECHNIQUE-2

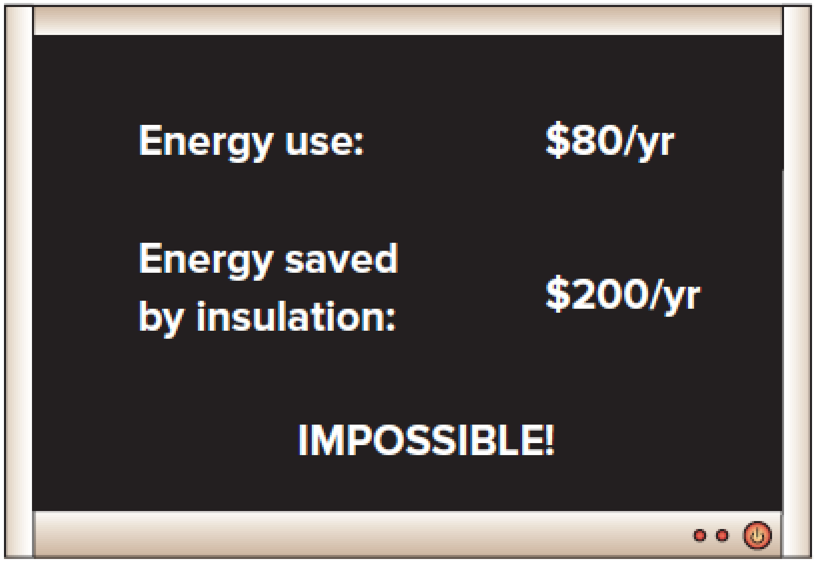


FIGURE 1–25
The results obtained from an engineering analysis must be checked for reasonableness.

FIGURE 1–26
Neatness and organization are highly valued by employers.

1-6 PROBLEM-SOLVING TECHNIQUE-3

FIGURE 1–27
An excellent word-processing program does not make a person a good writer; it simply makes a good writer a more efficient writer.

A Remark on Significant Digits

- **In engineering calculations, the information given is not known to more than a certain number of significant digits, usually three digits.**
- **Consequently, the results obtained cannot possibly be accurate to more significant digits.**
- **Reporting results in more significant digits implies greater accuracy than exists, and it should be avoided.**

Given: Volume: $V = 3.75$ L

Density: $\rho = 0.845$ kg/L

(3 significant digits)

Also, $3.75 \times 0.845 = 3.16875$

Find: Mass: $m = \rho V = 3.16875$ kg

Rounding to 3 significant digits:

$m = 3.17$ kg

FIGURE 1–28

A result with more significant digits than that of given data falsely implies more precision.

- Constant pressure (isobaric) P = constant
- Constant volume (isochoric) V = constant
- Constant temperature (isothermal) T = constant
- No heat interaction (adiabatic) $Q = 0$
- Constant enthalpy (isenthalpic) h = constant
- Constant entropy (isentropic) s = constant
- Adiabatic and reversible (isentropic) s = constant

Summary

- **Introduction to Thermal-Fluid Sciences**
  - Application areas of thermal-fluid sciences
- **Thermodynamics**
- **Heat Transfer**
- **Fluid Mechanics**
- **Importance of Dimensions and Units**
  - Some SI and English units
  - Dimensional homogeneity
  - Unity conversion ratios
- **Problem-Solving Technique**
  - A Remark on Significant **Digits**